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Random Probability Analysis of Recent ^{48}Ca Experiments

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Abstract. A Monte Carlo random probability analysis developed at LLNL for heavy element research was performed for recent experiments aimed at the synthesis of nuclides with $Z \geq 112$ and $N \geq 170$, to estimate the probability that observed decay chains were a result of a random event. Low probabilities ($< 10^{-4}$% for most decay chains) were found.

PACS. 27.90.+b Properties of nuclei A $\geq$ 220 – 02. Mathematical methods in physics

Since 1998, the Dubna-Livermore collaboration has performed extensive and lengthy experiments at the JINR U400 Cyclotron bombarding various actinide targets (^{238}U, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, and ^{249}Cf) with ^{48}Ca aimed at producing isotopes of elements 112-118[1] (see Fig. 1). The nuclides of interest, called evaporation residues (EVR) are separated from un-reacted beam, transfer products and other background reactions using the Dubna Gas Filled Separator, and are implanted into a position-sensitive Si detector array. Position-correlated decay events are observed in this detector during the beam-on (or beam-off) periods, which thus provides for a variable background counting rate in the detectors during the $\sim$ month-long experiments. Because of the influence of the closed shells at $N = 184$ and $Z = 114, 120$ or 126, the nuclides produced typically alpha-decay one or more times, before the decay sequence is terminated by a spontaneous fission (SF). Because of the low statistics involved in these experiments, often just one or two interesting events per month, and the long duration of the runs requiring stable operation of the accelerator and detection equipment, it is extremely important to understand the probability that the observed decay sequence might be merely due to a random event. Some estimates of these random probabilities [2] rely on average counting rates within the detectors or within position pixels defined by the detector position resolution for example, and thus are not able to consider variable backgrounds or counting rates.

A Monte Carlo method for estimating random probabilities was developed for these kind of experiments and is discussed more thoroughly in [3]. This method inserts a fission event (could be extended to a random alpha-decay) randomly in time and position into the *actual* data, and the same search algorithm used to locate decay chains of interest in the experiments searches for correlations with the random event, automatically including fluctuating background effects.

The results of the Monte Carlo random probability calculations are shown in Table 1. It should be noted that no attempt to eliminate decay chains on the basis of the semi-empirical Geiger-Nuttal relationship has been made in this study. Previously, many assumptions, such as which random number generator was used and non-uniform distributions of random fissions, were tested and found to have negligible effect on the calculated random probabilities [3]. Additionally, for the first element 114 experiment, the random probabilities calculated using this method were compared with other methods and generally found to be higher (thus more conservative). The search algorithm used in this study does not take into account decay chains with missing alpha-decays, decay chains with alpha-events in the side detector only (ie., no position information), or decay chains that span more than one file or run, which is typically on the order of a few hours. The element 115 SF with a half life of around 30h was handled differently. Generally, the parameters for the search algorithm were: EVR energy between 7 and 14 MeV, event positions ± 2 mm, alpha energies within a $1-2$ MeV window around the observed alpha-decay energies, SF energy > 130 MeV, and maximum correlation times variable depending upon the type of correlation (EVR-α, α-α, or α-SF). While counting rates vary depending upon the particular experiment, beam rates, detector positions and target thicknesses, typical counting rates within the $\pm$2mm position resolution for EVR-like events, for alpha-like events (beam on/beam off), and SF-like events are ~ 3 h^{-1}, (~ 1.5 h^{-1}/~ 0.7

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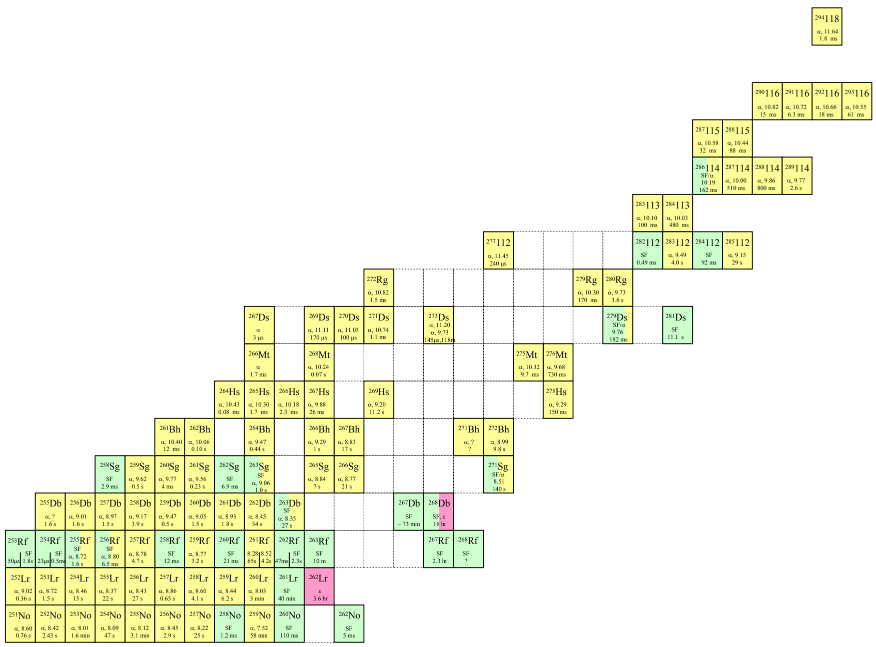

Fig. 1. Upper end of the Chart of Nuclides showing the isotopes synthesized within the last 6 years and their nuclear properties.

Table 1. Calculated probabilities that an observed decay sequence is due to random events for recent heavy element reactions. Note that because the overall decay chain duration is short for many of these isotopes, more random fissions may be required to ensure convergence of the method. These results are for $10-100$ million random fissions. In some cases, random probabilities are presented for shorter decay chains than actually observed (ie., decay chains with fewer alpha-decays), which already results in small probabilities that the observed decay chains are a result of randomness. Additionally, random probabilities for EVR-SF events were also calculated for all cases (not shown).

Initial isotope of decay chain	Production Reaction (^{48}Ca + ...)	Random Probability (%)
^{294}118	^{249}Cf	1.0×10^{-5} *
^{291}116	^{245}Cm	5.0×10^{-6} *
^{290}116	^{245}Cm	2.0×10^{-4} *
^{288}115	^{243}Am	1.5×10^{-4} *
^{289}114	^{244}Pu	0.172
^{288}114	^{244}Pu	8.6×10^{-4}
^{287}114	^{244}Pu	8.5×10^{-5}
^{287}114	^{242}Pu	4.1×10^{-4}
^{286}114	^{242}Pu	6.0×10^{-5}

*For decay chain with fewer alpha-decays than observed.

h^{-1}), and ~ 0.01 h^{-1}, respectively. For most chains, the probability that the decay chain is due to a random event is in the range of $10^{-4} - 10^{-5}$%, which is in general higher (more conservative) than other methods. The distribution of time differences between a randomly inserted fission event and the nearest preceeding EVR is shown in Fig. 2 for the ^{48}Ca + ^{245}Cm experiment. Note the location of the actual observed decay chains, much earlier in time than what would be the average of the distribution of random events. The position of the centroid can be estimated from the EVR-like counting rate for the ^{48}Ca + ^{245}Cm experiment of ~ 0.0039 s^{-1}. The time difference between EVRs in a detector position, averaged over the whole detector, is $\sim$ 300s – half this is the everage time interval between an EVR and a randomly inserted fission, namely $\sim$ 150s, which is consistent with the 244 s obtained from the Monte Carlo method properly taking into account all deviations from average.

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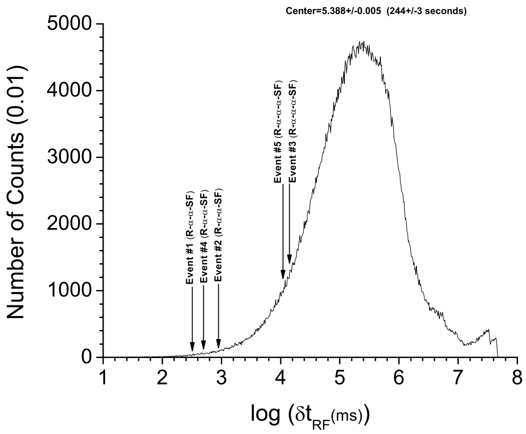

Fig. 2. Average time intervals between an implanted EVR and a randomly inserted fission for the ^{48}Ca + ^{245}Cm experiment and 1 million random fissions.